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**Visually Lossless Data Compression Technique for Real-Time  
Frame/Pushbroom Space Science Imagers**

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# Visually Lossless Data Compression Technique for Real-Time Frame/Pushbroom Space Science Imagers

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## ABSTRACT

A visually lossless data compression technique is currently being developed for space science applications under the requirement of high-speed push-broom scanning. The technique is also applicable to frame based imaging and is error-resilient in that error propagation is contained within a few scan lines. The algorithm is based on a block transform of a hybrid of modulated lapped transform (MLT) and discrete cosine transform (DCT), or a 2-dimensional lapped transform, followed by bit-plane encoding; this combination results in an embedded bit string with exactly the desirable compression rate as desired by the user. The approach requires no unique table to maximize its performance. The compression scheme performs well on a suite of test images typical of images from spacecraft instruments. Flight qualified hardware implementations are in development; a functional chip set is expected by the end of 2001. The chip set is being designed to compress data in excess of 20 Msamples/sec and support quantizations from 2 to 16 bits.

Keywords: Coding, lossy data compression, telemetry, space science applications, push-broom instruments

## 1. INTRODUCTION

The advances in sensors and detectors have culminated in a new era of scientific instruments for space applications. These new instruments combine unprecedented spatial and signal resolutions in addition to offering multi-spectral capabilities. The result is an increase in the volume of data that has to be collected, buffered, transported, and archived in the space-to-ground data system.

To alleviate the burden caused by the extra data volume, compression has been suggested and in some cases implemented on space platforms. However, scientists often object to any loss in the data and thus accept only lossless data compression. The amount of data reduction achievable with lossless data compression is usually limited by the inherent entropy measurement in the data, and for many remote sensing applications is limited to about two-to-one.

For other applications that require higher data reduction, as in quick-look or direct-broadcast sensor data, a lossy compression technique is needed. There exist various algorithms that provide good reconstruction performance at high compression ratios; however, none has adequately addressed the implementation requirement arising from push-broom instruments. A scan line of data produced by the push-broom type of sensor often exceeds two thousand pixels, and there is a limited amount of onboard buffering and processing time available before the data has to be transported for direct broadcast. In the following paragraphs, the requirements for space application of lossy data compression are stated, and then a description of a technique that meets all the requirements, along with its performance on several test images, is provided.

## 2. REQUIREMENTS FOR SPACE APPLICATIONS

Any implementation of lossy data compression on a space platform has to satisfy several requirements. These requirements were addressed by the Consultative Committee for Space Data Systems (CCSDS) Subpanel 1A Compression Working Group in 1998. The mandatory flight requirements are:

1. Process non-frame based (push-broom) as well as frame based input source data.
2. Offer adjustable data rate.

3. Work with large source quantization ranges up to sixteen bit-per-pixel (bpp).
4. Offer real-time processing at or greater than twenty Msamples/sec, and at less than one watt/Msamples/sec. The power consumption includes all buffering and support electronics.
5. Require minimum ground interaction during operation.
6. Allow packetization for error containment.

A coder that meets all the above requirements is described below.

### 3. DESCRIPTION OF THE CODER

#### Overview

The lossy coder consists of several functional modules depicted in Fig. 1. The scan converter takes input imaging data and formats it into eight-by-eight blocks of integer values as input to the de-correlator. The de-correlator employs a hybrid transform that performs a size-8 discrete cosine transform (DCT) in the Y direction of the imaging data and a size-8 modulated lapped transform (MLT) with sixteen input data points in the X direction. This hybrid transform, termed enhanced DCT (EDCT), uses overlapping blocks in the scan line direction to reduce the blocking effect inherent in a two-dimensional (2D) DCT, but it allows isolation of strips of eight lines, as is often required by practical implementation in a packet data system. However, the system also allows an eight-by-eight 2D DCT, an eight-by-eight 2D MLT, or other types of block transforms to be implemented.

The bit plane encoder (BPE) first groups the eight-by-eight transform domain components into three family trees; each has one parent, four children, and sixteen grand children. The magnitudes of components are scanned for any most significant bit (MSB) on the scanned bit plane. This bit-plane scanning proceeds from the top-most bit plane downward. The positional information of those identified components is represented by a family tree structure and may be further coded for efficiency. This information along with associated sign information is shifted to the output bit string from higher bit planes to lower bit planes.

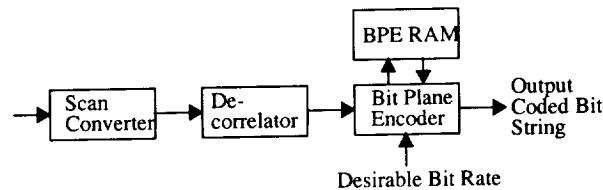


Figure 1. Functional Diagram of the Coder

The BPE random access memory (RAM) holds BPE-processed information for as many input blocks as it can support. The number of input blocks supported by this RAM is identified as one segment of input data. A segment can be as simple as one strip of eight lines, multiples of eight-line strips, or portions of a strip.

The output bit string constitutes an embedded data format that allows progressive transmission and decoding to start at a lower bpp rate and proceed to a higher bpp rate. The bit string can be terminated at a desirable rate for precise control of output data rate.

#### De-correlator

The EDCT is implemented by two one-dimensional transforms, the MLT and the DCT. The specified MLT takes sixteen input data points to provide eight transform components. The input is shifted by eight data samples each time a new MLT is performed.

The MLT is performed with the following equation:

$$X_m[j] = \sqrt{\frac{2}{8}} \sum_{i=0}^{15} x'_m[i] Z_m(i, j)$$

where  $m$  is used to index the MLT output block. The  $j$  index indicates the  $j$ th MLT component in block  $m$ . The input data sequence  $x[i]$  relates to the data samples in the above equation by:

$$x'_m[i] = x[(m - \frac{1}{2})8 + i]$$

The  $Z(i, j)$  function is given by:

$$Z_m(i, j) = -\sin[\frac{\pi}{16}(i + \frac{1}{2})] \cos[\frac{\pi}{8}(j + \frac{1}{2})(i + \frac{9}{2})] \quad 0 \leq i < 16$$

for all blocks except the first and the last. For finite input data, the first and the last MLT blocks are implemented with the boundary conditions in [1]. The DCT is computed by:

$$X[j] = \sum_{i=0}^7 x[i] A(i, j)$$

where  $A(i, j)$  is:

$$A(i, j) = C_j \sqrt{\frac{2}{8}} \cos[\frac{j\pi}{8}(i + \frac{1}{2})]$$

with  $C_j = 1/\sqrt{2}$  when  $j=0$  or  $C_j = 1$  otherwise.

### Bit Plane Encoder

The frequency components of each block are then scanned from the highest bit plane of their binary representations. At each bit plane  $nb$ , the purpose of the scanning is to locate components of magnitude  $\geq 2^{nb}$  but  $< 2^{nb+1}$  (the lowest bit plane is when  $nb = 0$ ) and transmit their locations in the coded bit string before the information of components at lower bit planes is conveyed. In this coding scheme, quantization is inherently performed by an increase of a power of two as scanning proceeds from higher bit planes to lower bit planes. To facilitate coding, a family tree structure at the  $nb$ -th bit plane, shown in Fig. 2, is used to help identify components and guide the component scanning.

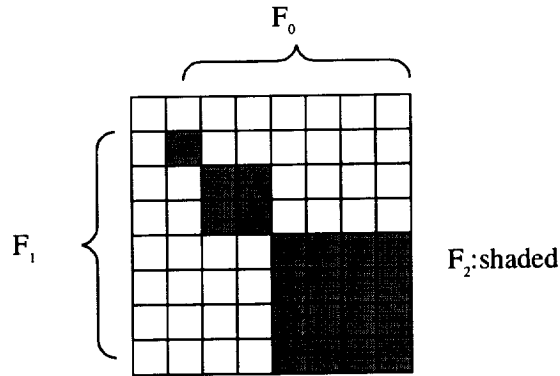


Figure 2. Family Tree Structure on One Bit Plane

### Family Tree Scanning

The tree structure in Fig. 2 consists of three family members:  $F_0$ ,  $F_1$  and  $F_2$ . Each has one parent, four children, and sixteen grandchildren. During tree scanning, these elements are grouped into different types of patterns and each pattern scanned as one entity. Thus parents will be scanned first, followed by the children and the grandchildren. The upper left component represents the DC component and is treated differently.

For each block, the family tree scanning starts at the highest bit plane of all the AC components. At a particular bit plane,  $nb$ , information extracted from all blocks is concatenated before proceeding to a lower bit plane. This procedure produces an embedded bit stream that starts with information from higher bit planes and proceeds to information from lower bit planes. At the desirable compression bit rate, the bit stream can be stopped for precise rate control.

#### 4. PERFORMANCE

The compression scheme has been tested on different types of imaging data (quantization 8~16) collected on space platforms with excellent results. In the test, every strip of eight scan lines was processed independently and a fixed compression ratio was obtained for each strip of data. Without any information carried over the strip boundary, error containment can be achieved within each strip.

In order to compare the GSFC technique with other commercially available algorithm, 8-bit image was used. The GSFC technique was compared with the current JPEG algorithm modified in order to specify a desirable data rate for eight scanlines. It included adjustment of the quantization values for every strip in order to remain close to the desirable rate. The peak-signal-to-noise (PSNR) in Figure 3(a) shows that the GSFC technique provides a gain of 1-3 dB for rate between 0.5 – 2 bpp. When both techniques are tested in frame mode, result in Figure 3(b) again shows similar gain of GSFC technique.

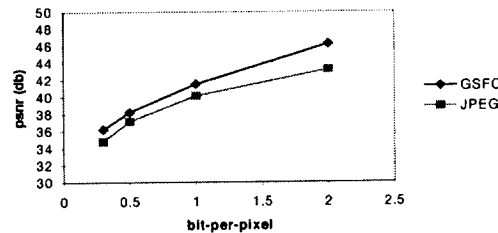


Figure 3(a) Strip Mode Performance

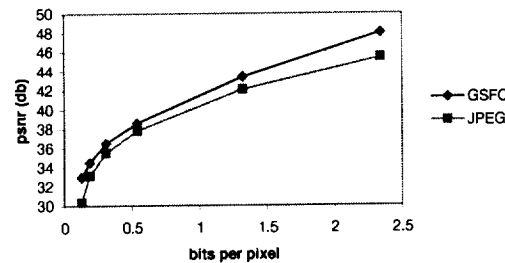


Figure 3(b) Frame Mode Performance

## 5. TECHNOLOGY STATUS

Rad-hard implementation of the compression scheme is being pursued. Currently, a custom VLSI chip for performing EDCT and the 2D DCT has been designed and fabricated. Its processing speed exceeds twenty-five Msamples/sec and it can process from 2 to 16 bits/sample. The VLSI architecture for BPE is under study. A functional chip is expected in 2001. The compression scheme is simulated in software and has been tested on various types of space data including NOAA/LRPT and MOLS/DMSP with satisfactory results.

## 6. CONCLUSION

A high performance lossy data compression scheme has been developed for space applications. This scheme offers real-time (over twenty Msamples/sec) processing on push-broom types of instruments. The technique produces an embedded bit string with the desirable features of precise rate control and no operator intervention.

## 7. REFERENCES

1. Henrique S. Malvar. *Signal Processing with Lapped Transform*. Norwood, Massachusetts: Artech House, 1992.